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TECHNICAL REPORT
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A STUDY OF SEAM LEAKAGE IN COATED FABRICS

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Edward S. Frederick
and
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Clothing and Personal Life Support Equipment Laboratory
TS-169

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A STUDY OF SEAM LEAKAGE IN COATED FABRICS

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FOREWORD

The soldier's personal clothing, equipage, and ancillary equipment are designed and engineered to provide, to the extent possible, maximum protection and comfort under virtually all climatic conditions which may be expected to be experienced throughout the world of military operations.

The problem of keeping a soldier dry in wet climatic conditions is, in one sense, the responsibility of the clothing system. Methods, whereby textile materials assume and accomplish this function, have received considerable attention over the years at the U. S. Army Natick Laboratories. From these efforts, new fabric weaves and water-repellent finishes have resulted in significantly improved materials, clothing items and tentage which can protect the soldier in wet environments.

Leakage of moisture through seams, however, has been shown to be a persistent problem not easily resolved. Nevertheless, even here, significant improvements have been realized by the introduction of water-repellent thread and selected seam constructions. With the introduction of lightweight coated fabrics, special problems arose somewhat different from uncoated fabrics. Coated fabrics, being essentially a homogeneous organic polymeric matrix laid upon a base fabric, at sewn seam junctures, are particularly vulnerable to moisture leakage. Present techniques to prevent leakage at sewn seams of coated fabrics require a post hand-sealing operation which involves several applications of a selected sealant laboriously applied to one or both sides of the coated fabric sewn seam.

The purpose of this study, therefore, was to investigate and better understand the problem of moisture leakage through sewn coated fabric seams. From an improved understanding of this problem, it was hoped that available avenues could be developed that would make it possible to construct sewn seams in coated fabrics, particularly in ponchos and raingear, that would eliminate the need for post-sealing treatments.

The assistance of Mr. Alan McQuade, Chief, Chemical Modification of Textiles Branch, Clothing and Personal Life Support Equipment Laboratory and members of his staff, Messrs. Stanley J. Shurtleff, Charles Macy, and Walter Koza is hereby acknowledged with appreciation.

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ABSTRACT

Extensive investigations of sewn seams in coated fabrics have been conducted. The relative role of thread, sewing machine components, stitch and seam types and properties of fabrics have been evaluated as parameters involved in seam leakage. Utilization of various experimental seam constructions, gasketing, application of heat during seam sewing and other techniques were attempted as potentially useful approaches in combating seam leakage.

Results indicate the main source of leakage, under experimentally generated hydrostatic pressure conditions, to be in the folds of the fabric and the needle holes generated in the sewing operation. Post sealing, accordingly, must be considered to be a necessary requirement for all coated fabrics to assure moisture-proof seams under field use conditions.

SEAM LEAKAGE IN COATED FABRICS

1. Introduction

Currently, military specifications(1) for items fabricated from coated fabrics require that seams be sealed with a minimum of three coats of sealant made from the same material as the coating. This procedure, if carried out properly, will result in a seam sealed coated fabric that will pass the additional low pressure hydrostatic test requirement of 50 CM for ten minutes (0.74 pounds/square inch).

The requirements described above have created a number of practical difficulties for manufacturers of coated fabric items, not the least of which is the considerable space required to lay out flat, large numbers of large items like ponchos for sealant application and drying. Large-scale procurement of such items multiplies the space requirements accordingly. In addition, unless the sealant is applied very carefully, the hydrostatic test requirements are not met and the items are subject to rejection. The sealing operation is, thus, a time-consuming and expensive operation, in some cases representing as much as 15 percent of the total cost of the item.

In an attempt to alleviate some of these difficulties, a study was initiated to determine alternate methods of seaming. Coated fabrics could be developed which would bypass the need for a hand-sealing operation and will at the same time meet the current military specifications in regards to resistance to water penetration.

2. Causes of Seam Leakage

a. Wicking of Thread

The puncture of a coated fabric by a sewing needle is the initial dramatic action responsible for the problem being considered here, namely, moisture penetration. Even when the needle hole is immediately filled with a hydrophilic fiber thread such as cotton, capable of swelling when wet to fill the newly fused hole, leakage will take place due to a wicking action of the sewing thread.

Wicking, f the purposes of this study, can be considered the movement of along the longitudinal axis of the thread. Figure 1 shows a typical wicking action of thread in a seam with two rows of stitches. The wicking action in terms of rate and quantity varies with the variable constructions of sewing threads and with the basic molecular configurations of the fiber or filament.

Figure 1. Example of Wicking

Threads, in terms of construction, may consist of two or more plies of yarn twisted together or multi-plied in which several strands of previously plied yarns are twisted together to form the final thread.

In the man-made fiber threads, yarns containing merely the fiber producer's twist (less than 1 turn) are twisted together in many plies (as high as 12) with less than three turns of twist per inch to form a final thread closely resembling a single-ply thread.

Either hydrophilic or hydrophobic fibers or filaments may be chosen for thread. Man-made fibers or filaments are generally hydrophobic except viscose rayon, which is hydrophilic. The natural fibers such as cotton and linen are hydrophilic. The hydrophobic fibers or filaments will repel water, but under certain circumstances will hold it mechanically.

When any of these fibers or filaments are spun and twisted into textile yarns or thread, they will transport water through the longitudinal axis of the structure. As threads, the hydrophobic filaments or fibers will transport water in a vertical or horizontal plane through the mechanism of capillarity. In yarns or threads made with the hydrophilic or absorbing fibers or filaments, the water is transported by absorption as well as by capillarity.

Factors other than hydrophobicity and hydrophilicity also must be considered. Smooth fiber surfaces, as for example, with glass filament yarns, generally have high rates of capillarity. The amount of twist in a thread can be related to capillarity. Twisting a thread creates small channels between the fibers and thread plies and increases the tendency for capillary attraction.

Vertical rise wicking tests were made for five different threads. Figure 2 shows curves taken from typical test data. The end point of the test is reached when no further rise is measurable after extended time periods. All the threads compared here were chosen to be as similar in size or diameter as possible. Curves are shown for two spun polyester threads of the same physical characteristics, the only difference being that the thread with the higher rise contained a hydrophilic ingredient in the sewing finish.

Hydrophilic filament threads, such as rayon, have a faster rate of capillarity than the hydrophobic filament polyester of approximately the same physical characteristics (size, ply, filament, etc.). The total rise is greater over extended periods of time,

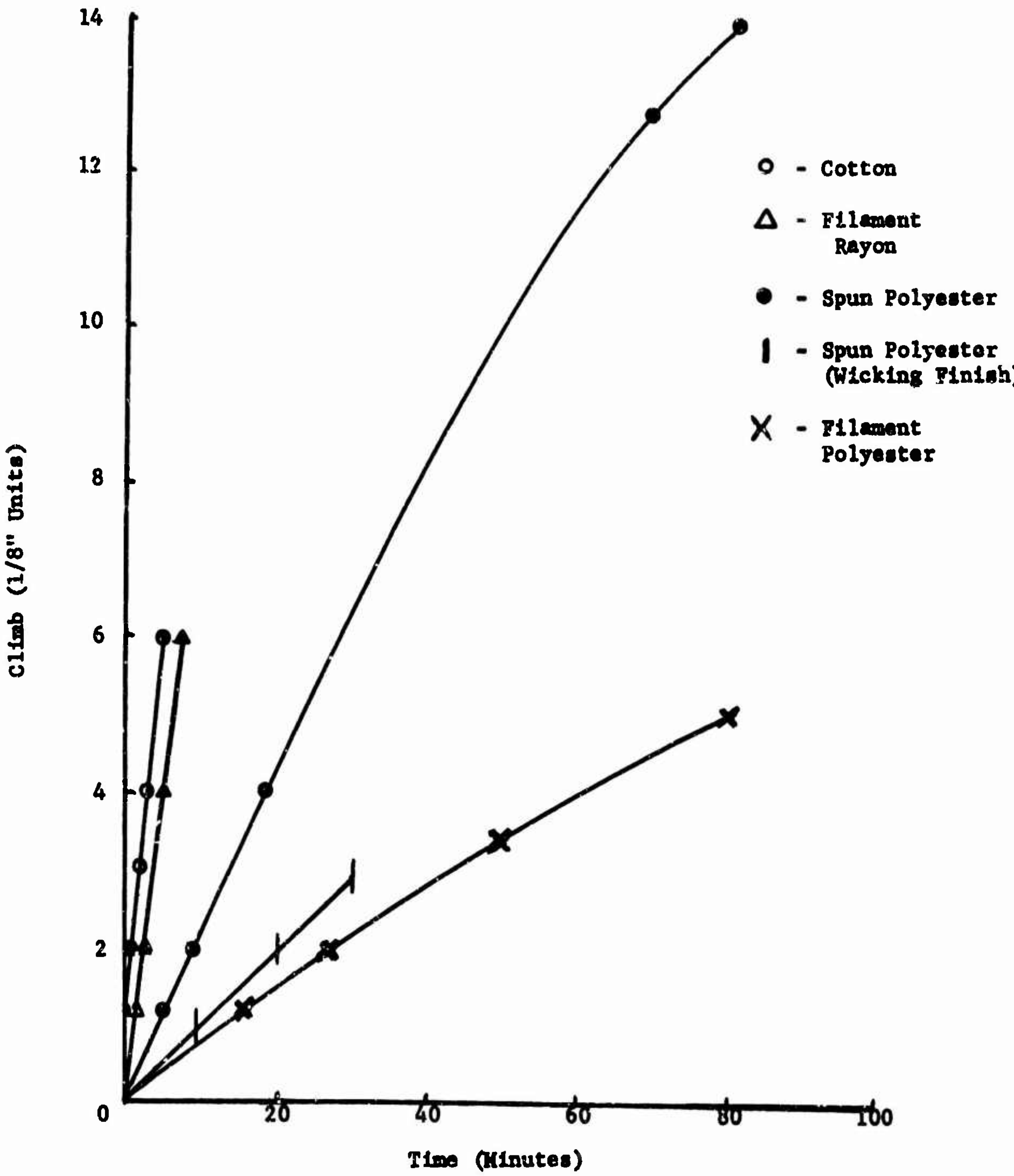


Figure 2. Comparison of Wicking Rates of Various Threads

however, for the hydrophobic threads. Threads spun of hydrophobic fibers have about the same rate of capillarity as the hydrophobic filament threads, but the height to which the water will rise over long periods of time is greater for the filament threads. The rate of capillarity for cotton thread is greater than for any of the synthetic fiber threads.

Rayon filament thread swells when wet (Figure 3a). This swelling, because of the interaction of the twist, causes the thread to contract in length. When the thread is allowed to dry, the fibers assume their normal size, the air spaces among plies of yarn and among the filaments increase substantially, but the lengthwise contraction of the thread remains. When the same thread is tested with a weight on one end (Figure 3b), shrinkage does not occur since the constraint imposed by the weight tightens the twist and will not allow the fibers to swell to the same degree. As a result, when the thread is allowed to dry with the weight still in place, the distortion of the thread is minimal. The weighted thread illustration is analogous to thread under tension in a seam; thus, studies of hydrophobic filament and fibrous thread in seams show no measurable swelling or shrinkage.

The effect of knots in the threads was also studied to determine if the capillarity is affected by knots. Simple single overhand knots (simulating to some degree the interlacing of thread in the stitch type 401) were made in the threads described above and were exposed to both vertical and horizontal wicking tests. The knots slowed down the migration of the water considerably through the rayon filament thread. In the low twist synthetic threads, the migration through the knots was at about the same rate as through the unknotted portions. The passage of the water through the knots of the highly twisted synthetic thread was somewhat slower.

In most of the synthetic threads, the knots apparently had no effect on the rate of passage of water. The water used for these tests contained a small amount of pure blue direct dye used as a tracer. By this method, it was relatively easy to follow the flow of water through the threads when tested horizontally. However, when the threads were tested vertically, the water rose at a much faster rate than the dye after the first few minutes. Tracing the flow of the colored water through the rayon filament thread revealed that the water crept between the plies of the thread faster than it was absorbed by the fiber. This was confirmed by microscopic observation of the thread after drying. Color was apparent between filaments and plies although the filaments were not stained.

a b

Figure 3. Swelling of Rayon Filament

Additional observations on the wicking of thread structure were made with a series of loops of thread. This was to show how the water might be transferred from the exposed thread on the outer surface of the seamed fabric to the protected thread on the underside of the fabric. Minor[2] has stated that the transfer of liquid in yarns crossing each other forms a new reservoir which feeds both branches uniformly. A strand of the thread was knotted to form a continuous loop. Another strand of the same thread was passed through the first loop and knotted to form a second loop. (This represents approximately the condition of thread sewn in the standard type 301 stitch and is similar to the interlooping of the looper or bottom thread of the type 401 stitch.) One loop was suspended from a laboratory stand over a battery jar of colored water. The other was weighted and immersed in the water bath with a catenary submerged two inches below the surface of the water. The water, as expected, climbed up both sides of each loop at the same rate. When the liquid reached the interlacing of the two loops, it transferred from the submerged loop to the suspended loop and travelled outward and upward equally from this point up each strand of thread in the suspended loop.

<u>Migration of Water Through Threads Sewn Into Water-Repellent Fabrics</u>

To learn more about the migration of liquid through seams, the cotton, rayon, and polyester threads were hand-sewn through a very tightly woven cotton warp-rayon filled tentage fabric treated with a very effective metallic salt-wax-type, nondurable, water-repellent compound. It is common belief that when threads made of swelling fibers are sewn into seams, they will swell when wet and fill up the needle hole to prevent leakage. Apparently, little thought has been given to the migration of water through the thread after it is wetted and allegedly swelled. A hand-sewing needle 0.080 inch in diameter was used to pass a loop of each thread through the fabric. The loop was drawn approximately three inches below the bottom surface of the fabric and a 3/4 ounce weight was placed in the catenary. The fabric was suspended over a laboratory jar so that the weighted loops were submerged two inches. The ends of each of the loops were left two inches long and were laid horizontally on the top surface of the fabric. One inch squares of blotting paper were laid under the ends. The rate of wicking of the threads was measured in terms of the time required for water to pass through the fabric and wet the blotters.

This testing showed that the rate of travel of water through the fabric was no different than the rate at which it travelled up the strands until it reached the under surface of the fabric. It is

obvious from this test that the migration of water will take place through absorptive materials in a seam despite the fact that swelling might occur to further jam the needle holes. It was also obvious that the man-made hydrophobic filament threads transported the water at a slower rate than the rayon filament or the cotton threads.

Cotton threads treated with Quarpel[3] and polyester thread treated with a nondurable water-repellent finish were also tested to determine the effect of water-repellent finishes on the wicking properties of thread. None of these threads showed any signs of wicking over long periods of time, though all other threads tested showed wicking. Thus, despite the size, type of fiber or filament, twist, and other mechanical properties of the thread, water-repellent treatment is a necessary requirement for the thread used in any water-repellent system.

b. Process of Sewing

When a sewing machine needle is plunged through a tightly woven fabric engineered to be wind and water-resistant, it is not a simple problem of separating the yarns in the fabric to deposit the two strands of thread left in each needle hole. The yarns are so tightly woven together that they have no place in which to move; therefore, they are actually cut across their width by the needle. This leaves the ends of yarn which are carried through the fabric to the underside with the needle and are brought back to the surface of the material when the needle and thread are withdrawn. Evidence of this is particularly noticeable in fabrics which have poor dye penetration: the cut ends of the yarns show up as light specks along the line of stitching. These cut ends, along with the other yarns in the fabric, press against the strands of thread left in the needle hole. The needle hole, as a result, is closed with some compressive force around the thread. In Figure 4, typical needle holes are shown after the thread has been withdrawn. The cut ends of yarn now fill the holes as a result of the release of these compressive forces.

The mechanical properties of the thread in a seam must be considered concurrently with making seams water-repellent. The seams of water-repellent items must be engineered to provide the strength required by the end item as well as providing for water resistance. Thus, the size thread and stitches per inch are selected for the desired seam strength. The needle is then chosen to fit the required thread in its eye and groove. The eye and groove of a standard needle is approximately 27 to 33 percent of the diameter or width of the needle. Therefore, the largest size

Figure 4. Cut Ends of Fabric Yarns Closing Needle Holes

thread in bulk that can be used is about one-third the diameter of the needle, allowing for some compression of the thread in the eye. The eye of the needle is an oblong slot (Figure 5) about twice as long as it is wide, so that a compressible thread has room to flatten out.

The thread, then, is about one-third the size of the needle hole made in the fabric, disregarding that the tightly woven fabric will recover from the deformation of the needle and close around to neck the thread even though one or more yarns are cut. When the needle passes through the fabric, it carries two strands of thread through with it. In the stitch type 301 the loop of needle thread is interlaced or twisted around the bobbin thread 1/2 turn and a loop is formed that is pulled up into the material sewn, when the material is sufficiently thick to permit it. Thus, when the needle is withdrawn from the fabric, it leaves, theoretically, not two but four strands of thread in the needle hole (Figure 6a). Considering that the single strand of thread is one-third the diameter of the needle and the ensuing hole left thereby, the amount of uncompressed thread left in the hole is equal to one and one-third times the size of the needle or hole. However, the cross sections of the threads are not solid masses or rods and in the uncompressed state may consist of 50 percent air.

In the other popular stitch for industrial sewing, type 401 (Figure 6b), a loop of the needle thread is passed through the fabric and interlooped twice with the looper thread. Unlike stitch type 301, the underthread is not pulled up into the fabric but forms a tight knot-like structure with the needle thread, which is pulled up to, but not into, the needle hole on the undersurface of the fabric. This knot will tend to block off the needle hole because it is larger than the hole.

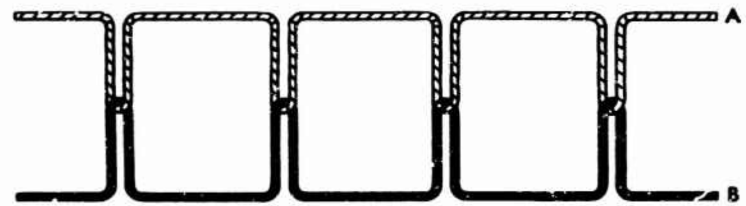
The principal observation is that the needle hole is well filled with thread as the stitch is made. Therefore, water of normal surface tension could be expected to have a difficult time passing through the needle holes in a tightly woven, well-treated, water-repellent textile fabric. The capillaries, however, have been reduced and thus the force of capillary attraction potentially increased. Under the forces of the hydrostatic pressures involved the needle holes may be expected to increase in size.

c. Effect of Machine Components

(1) Needle

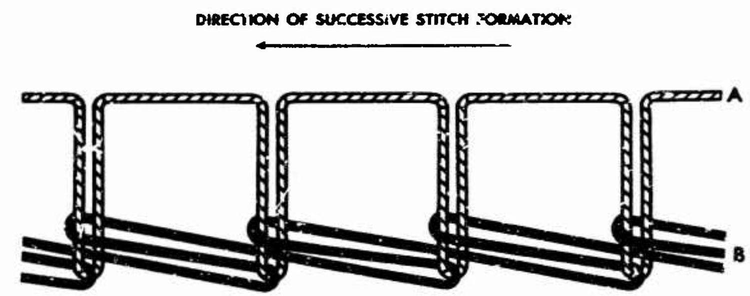
In addition to the standard round point (also called cloth point), needles are made with a variety of cutting points, such as triangular point, diamond point, and spear point. All of

Figure 5. Shape of the Needle Eye



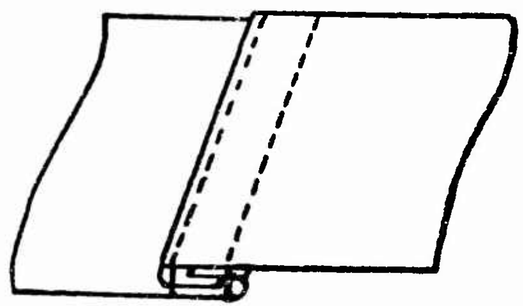
STITCH TYPE 301

a.



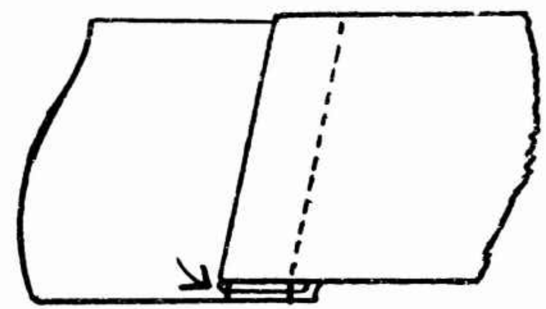
STITCH TYPE 401

b.



SEAM TYPE LSc-2

c.



SEAM TYPE LSq-2

d.

Figure 6. Stitch and Seam Types

these needles inflict greater fabric damage and, as a result, generate more heat than the straight round point needle. The larger the needle, the greater the damage to the fabric and the higher the heat generated.

The strength required by the end use of the item is of paramount consideration in engineering a seam and, therefore, needle size must be considered carefully. Increasing the number of stitches per inch so that the finest thread and needle can be used is generally advantageous. Thus, twelve small holes per inch rather than six large ones would be more desirable. The minimum size of needle that can be used will depend upon the resistance of the fabric. The force required to push a needle through a dense coated fabric and cross previously made seams can be great enough to cause a fine needle to deflect, skip stitches or even break.

Multiple plunging of a needle through the folds of material in a seam tears holes in the fabric. The pressure of the presser foot on the fabric can be very high but nevertheless is necessary to insure proper feeding. This causes the fabric under the foot to compact. Specific coatings vary; however, polyvinyl chloride coatings which have high coefficients of friction resist sliding over machine surfaces and make the feeding in the sewing operation that much more difficult.

The coating and the clamp formed in the machine between the presser foot and the throat plate prevent the fabric yarns from moving away from the plunging needle and they are consequently cut through. The standard round point needle acts like a wedge, having a very small point which increases over a very short length to widths of 0.040 to 0.050 inches across the eye. When the point first enters the material, the wedge part of the needle attempts to separate the yarns at very high rates of speed. The yarns cannot deform at this rate and the very short lengths captured in the clamp cannot elongate sufficiently to afford the greater length of yarn required to pass around (1/2 circumference) the needle. The yarns thereby can fail in tension. This resistance of the fabric to open for the passage of the needle is responsible also for the heating of the needles.

(2) <u>Throat Plate</u>

The throat plate of the machine generally contains the feed and the hole through which the needle (after going through the fabric) must pass to present the loop of needle thread to the loop taker of the sewing machine. On light to medium heavy machines making stitch type 301, these holes are round. Heavy machines with needle feed mechanisms have an elliptical hole in the feed to permit travel of the needle. On machines making the stitch type 401, the

shape of the plate hole is also elliptical. The reason for this shape on the latter machines is to allow the chain made on the back of the seam to pass from beneath the plate to the top surface.

The size of the throat plate hole must be reasonably close to the size or diameter of the sewing needle. If the throat plate hole is too large, the descending needle forces the fabric into the hole and makes it more difficult for the needle to pass through, resulting in greater fabric damage and higher needle heat.

If the throat plate hole size is regulated with a clearance of approximately 0.015-inch (for a needle 0.040-inch, the throat plate hole would measure approximately 0.055-inch), the clamping between the presser foot and the throat plate over the hole will be more effective and fewer fabric yarns will be cut at each needle penetration than with a large throat plate hole.

(3) Presser Foot

In addition to controlling the size of the throat plate hole, it is also important to have a correctly shaped presser foot. It first must match the shape of the feed. Also, the clearance between the toes and the needle should not be any greater than the clearance between the needle and the walls of the throat plate hole.

Besides helping to form the feeding clamp, the presser foot must also push the fabric off the needle as the needle rises. If the clearance between the toes of the foot and the needle is large, the fabric is dragged up between the toes of the foot by the needle and damage can be incurred here as the needle is pulling out of the fabric.

Everything which takes place in a sewing machine operation occurs at a high rate of speed. Machines are often run at top speed, even in some cases exceeding the speeds recommended by the sewing machine manufacturers. The above factors become even more critical as the speed of the machine increases.

(4) Feeds

Talc and mica dusted on the fabric, to offset tackiness after coating, affords some lubricity to the fabric surfaces during the sewing operation. Unfortunately, most of the dry lubricants are dusted off in the cutting and handling of the fabric. In order to obtain a proper feed or flow of the material through the sewing machine, fabricators have found it necessary, therefore, to apply wet lubricants to the edge of the materials as they are being sewed.

It has been determined through proper testing that specific lubricants such as water and isopropyl alcohol have no adverse effect on the coating, the water-repellent tr tment of the thread in the seams, and the sealing of the seams.

On long seams on the lightweight poncho, close coupled pullers (two superimposed rollers, one driven, behind the presser foot) or driven top roller pressers will augment the feed of the machine and eliminate the need for lubricants. Many manufacturers do not evaluate the augmenting feeds properly and do not have pullers or roller feeds. Thus, a combination of the high presser foot pressure and the drag of the feed tends to cause great damage to the fabric as the needle is driven through. This high presser foot pressure also causes the serrated feed dog, particularly when new, to puncture the coating and expose the base fabric yarns (Figure 7) and/or scrape and peel it from the fabric. This damage can be prevented by honing the sharp edges of the feed, setting it lower in the machine, and employing one of the augmenting feeds.

Additional damage in the area of stitching is caused by sewing thread abrasion of the fabric edge of the needle holes as one stitch is being set and the fabric advanced for the succeeding stitch. This damage can be reduced by employing needle feed machines with compound feed and/or alternating pressers.

3. Leakage Through Coated Fabrics

a. Fabric Properties

The role of the fabric in producing water-resistant seams is as important as that of the thread. The fabric must be well-treated (if a tightly woven textile fabric) so that low surface energy is developed to cause droplets of water to form beads with high surface contact angles. This phenomenon causes the normal water to bridge the hole made by the sewing needle and prevent its seepage through the folds of the seams (Figure 8). Thus, seams can be made in this type fabric (all cotton poplin treated with Quarpel) with water-repellent thread that will withstand shallow static water up to 0.036 psi for very long periods of time. Seams made with Quarpel-treated cotton thread in Quarpel-treated raincoat fabrics have withstood simulated rainfall of one inch per hour for more than seven (24 hour) days. Tents of cotton duck with good water-repellent finishes sewn with nondurable, water-repellent polyester thread have withstood simulated rainfall of one inch per hour for similar periods of time.

Figure 7. Feed Punctures
Exposing Fabric Yarns

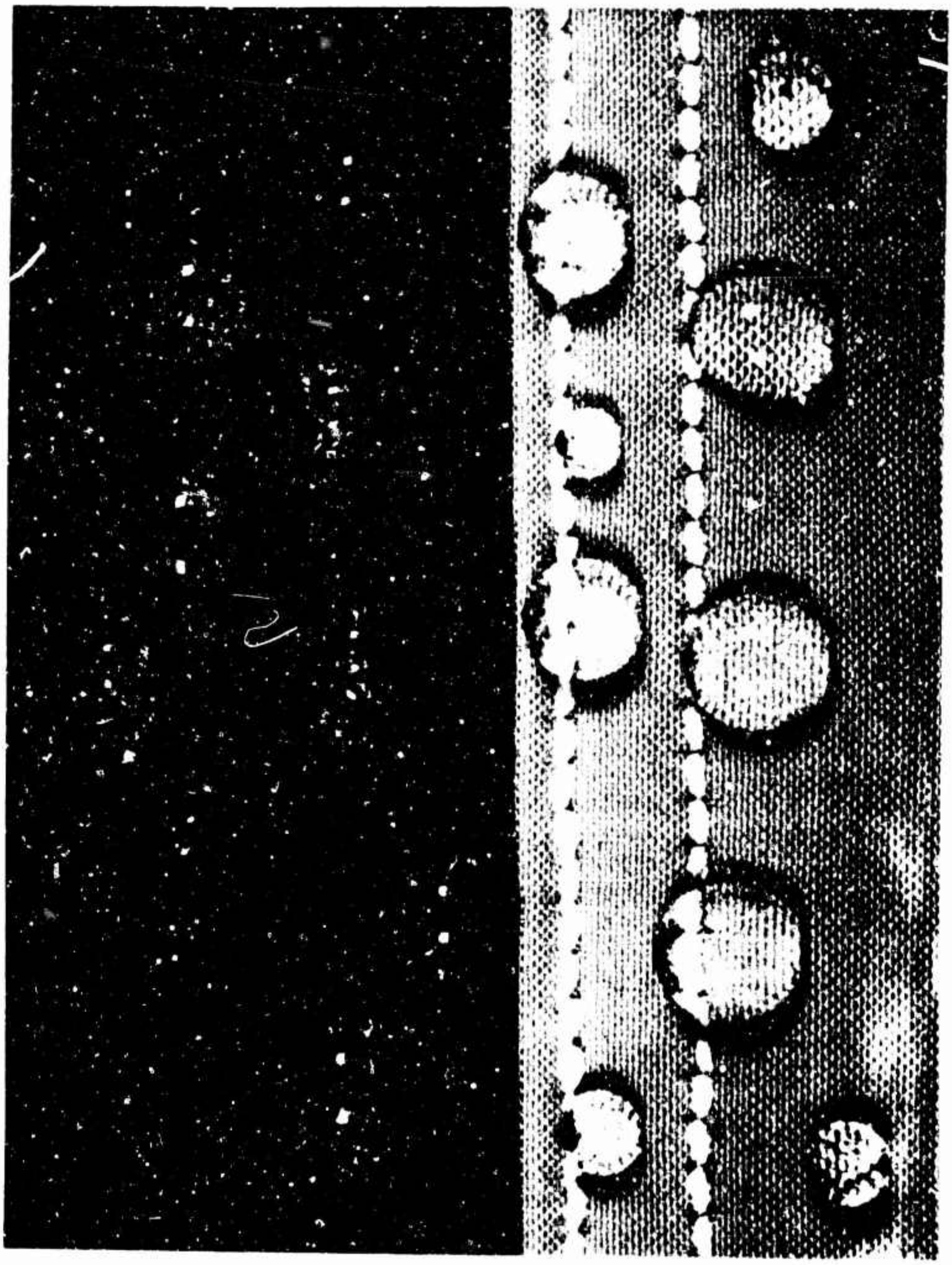


Figure 8. Beading of Water on Low Surface Energy Poplin Fabric and Water-Repellent Thread

Even textile fabrics and seams sewn with water-repellent thread will not withstand high hydrostatic heads of water for any measurable period of time. Table I, column 1 demonstrates this fact by comparing the hydrostatic resistance of three military clothing fabrics treated with Quarpel and a cotton duck treated with a nondurable-type water repellent. Even though these fabrics showed high hydrostatic resistance, leakage occurs almost immediately.

The best seam (column 2) was type LSc-2-401 in the 9-ounce cotton sateen (Figures 6b and 6c), sewn with 12 stitches per inch and Quarpel-treated thread, which withstood pressure of only 36 cm. The effect of the needle holes stands out quite clearly when columns 1 and 2 are compared.

TABLE I

COMPARATIVE HYDROSTATIC RESISTANCE OF WATER-REPELLENT MILITARY FABRICS AND SEAMS

Fabric	1 Fabric (cm)	2 Seams (cm)
9 Ounce Cotton Sateen, Quarpel Treated	46	.36 1/
5.5 Ounce Cotton Warp - Nylon-Filled Oxford, Quarpel Treated	55	35 1/
5.0 Ounce Cotton Poplin, Quarpel Treated	56	32 1/
12.29 Ounce Cotton Duck, FWWMR,* nondurable treated	40	30 2/

1/ LSc-2 seams sewn with 12 stitches per inch Quarpel-treated thread.

2/ LSa-1 seams sewn with nondurable, water-repellent-treated, polyester thread.

b. Vertical Wicking Test

The vertical rise wicking test was conducted as follows: Specimens were cut one inch wide and approximately 10 inches long. One end of each specimen was fastened to a horizontal arm on a laboratory stand above a jug of water. A weight of approximately 3/4 ounces was attached to the other end of the strip. The strips were lowered into the water until the weighted end was two inches below

the surface. The time of entry of the strips into the water was recorded and observations were made at 5 minute intervals for the first 15 minutes, and at 15 minute intervals thereafter. The rise was measured to the nearest 1/16-inch. The results are shown in Table II.

TABLE II

COMPARISON OF THE VERTICAL WICKING OF WATER-REPELLENT TREATED AND NON-WATER-REPELLENT SINGLE COATED FABRIC

Fabric Time/Mins	Rise in 1/16 Inches Untreated	Treated
5	2	0
10	4	0
15	6	0
30	10	0
45	11/16	0
60	12/16	0
75	12/16	0
90	12/16	0
Overnight (17 add. hours)	No change	0

The water began to climb on the untreated fabric specimens immediately on contact with the fabric and progressed to a point 3/4 inches above the water level after 60 minutes. The specimens showed no change after two additional 15 minute periods. The specimens were left exposed overnight for an additional 17 hours and showed no change. On the other hand, no wicking was detected on the water-repellent treated specimens after the entire exposure of 18½ hours.

c. Mechanisms of Seam Leakage

Two types of fabric were employed in this study. One was a 1.1 ounce, rip-stop, nylon base fabric coated on one side with a polyurethane coating having a total weight of 2.5 to 3.25 ounces/square yard. The second was a nylon twill base fabric coated heavily on one side and lightly coated on the other with polyvinyl chloride, a total weight of 6 to 7 ounces/square yard.

In sewing, both fabrics have individual characteristics. Both coatings are thermoplastic. Each will melt in high-speed sewing when needle heat is generated which exceeds the melting point of the respective coatings. The lightweight material produces very little needle heat when sewing four layers at high speed, as its density and thickness are relatively low. On the other hand, the double-coated fabric drags in the machine, retarding the feed. It is heavy and dense; thus, considerable force is required to plunge the needle through four plies of this material. The result is that high needle heats are generated and the coating is melted. In nearly all cases, the base fabric yarns are severed by the needle. It is likely that some of the yarns are melted by the hot needle. In any case, gaping holes are left in the fabric after the sewing thread is withdrawn (Figure 9).

Unlike woven textile fabrics, in which some means for removing the manufacturing tensions such as heat setting or sanforization (compressive shrinkage) are used, coated fabrics are coated under longitudinal stress. The yarns in such fabrics are never permitted to relax as the coating fills the interstices. When the yarns are cut in sewing, they do relax, however, and withdraw from the point of penetration to cause a hole. Additionally, the hot needle melts the thermoplastic coating which shrinks and further opens the hole left by the needle.

While the sewing needle is essentially round, the hole left in the fabric is more of an oblong slot. The needle is neither a punch nor a drill and does not remove material in making a hole. It merely pierces the fabric and pushes the yarns aside. When the sewing thread is deposited in the type of materials studied here, the tension of the thread pulls on the edges of the hole to enlarge it (Figure 10). This material, which is both essentially inelastic and fused around the needle hole, will not permit the yarn around the hole to close and neck off the thread to prevent seepage of water as would happen with uncoated woven fabrics.

Figure 9. Needle Holes in Double Coated Fabric

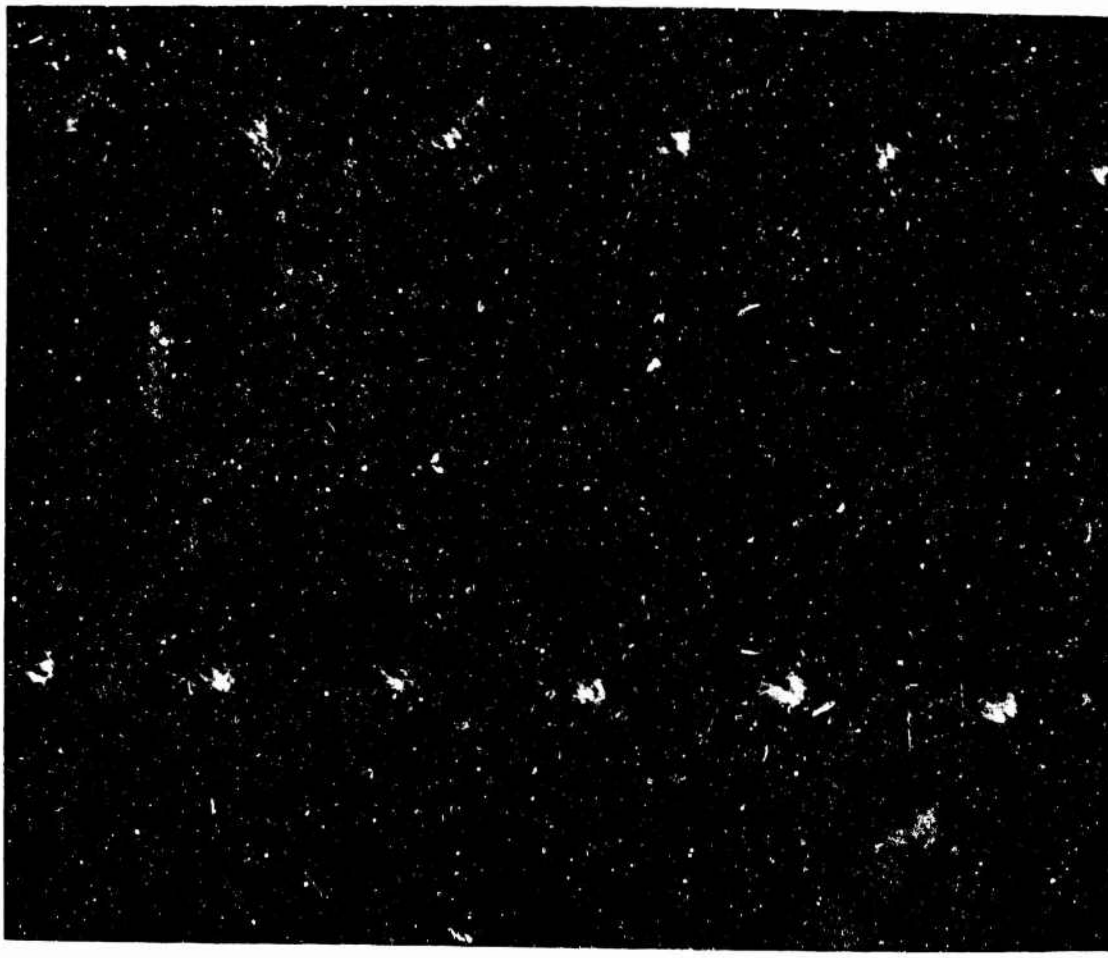


Figure 10. Thread Tension Holding Needle Holes Open

While coated fabrics are waterproof, their surface energy is high. Therefore, water dropped on them will not form beads but will flow freely. Typical beading is shown in Figure 8. The difference here is similar to the effect seen on an automobile surface before and after wax polishing. The low surface energy of the coated surface will permit the water to seep through the small apertures of the needle holes around the thread and flow between the folds of fabric in the seam (Figure 10). Additionally, the cut ends of the fabric yarns which project through the needle holes will wick water through to the underside of the seam. If water-repellent thread is not used in the seams, the thread will also be a source of leakage by wicking water through the seam.

4. Tests of Sealed and Unsealed Seams

a. Jar Test

The problems of seam leakage encountered with single coated fabrics, with raincoats made of a 1.6-ounce nylon twill fabric coated on one side with polyvinyl butyral, having a finished weight of approximately 3.6 ounces/square yard have been considered in an earlier report(4).

This study showed that the uncoated side of the fabric had high capillarity. When seams made into this fabric were suspended over the mouth of the battery jar (Figure 11) and one inch of water was placed on the uncoated side, the water travelled through the folds of the fabric at such a high rate that it was impossible to measure. The water also flowed by capillarity up the sides of the fabric, over the edge of the jar, and dripped onto the laboratory bench.

A nondurable-type water repellent was applied to a sample of this fabric to determine if the capillarity of the fabric surface could be eliminated. Seam specimens were made in both the non-water-repellent and the water-repellent treated fabric with non-water-repellent and water-repellent treated thread. Seam type LSc-2 (Figure 6c) was used as the test seam. The seam specimens described and identified in Table III were subjected to the jar test.

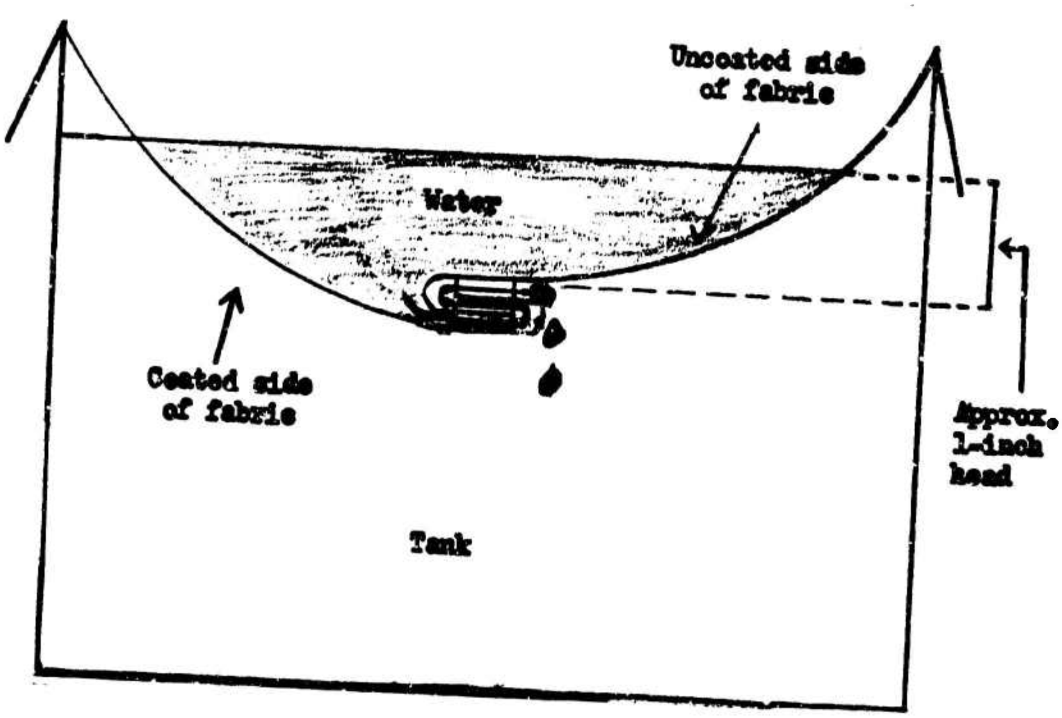


Figure 11. Water Seeping Through Folds of Fabric

TABLE III

SUMMARY OF SEAM LEAKAGE TESTS

Specimen No.	Kinds of Seams Tested: Fabric	Kinds of Seams Tested: Thread	Initial Mechanisms of Leakage: Time	Initial Mechanisms of Leakage: Location
1	Standard	Standard	Immediately	Folds of fabric needle perforations and/or thread wicking
2	Standard	Water repellent	Immediately	Folds of fabric
3	Water repellent	Standard	55 minutes	Needle perforations and/or thread wicking
4	Water repellent	Water repellent	None after 48 hours	None

In the jar test (Figure 12), the seam specimens were suspended horizontally over the opening of oblong-shaped jars (approximately 8 inches wide, $11\frac{1}{4}$ inches long, and $8\frac{1}{2}$ inches deep), with the cloth side of the specimen up. The horizontal plane of the fabric was depressed approximately $1\frac{1}{2}$ inches below the top edges of the jars to form a basin. The edges of the material were draped over the edges of the jars and securely and uniformly fastened by clamps on all sides. Approximately one inch of distilled water at room temperature was poured slowly with the least possible impact into the basin formed by the fabric. The time of entry of the water was recorded and immediate observations were made.

Test results (Table III) showed that the water came through the seams in the standard untreated fabric and thread specimens almost immediately (Figure 13), (Specimen #1). Study of the seam revealed that the thread darkened in color, indicating that it was absorbing the water readily. Water was observed seeping through the needle holes. This could have been wicked through by the thread, the cut ends of the fabric yarns, or forced through the holes by the pressure (0.035 pounds/square inch) of the water on the specimen. However, it was observed that water was seeping between the layers of

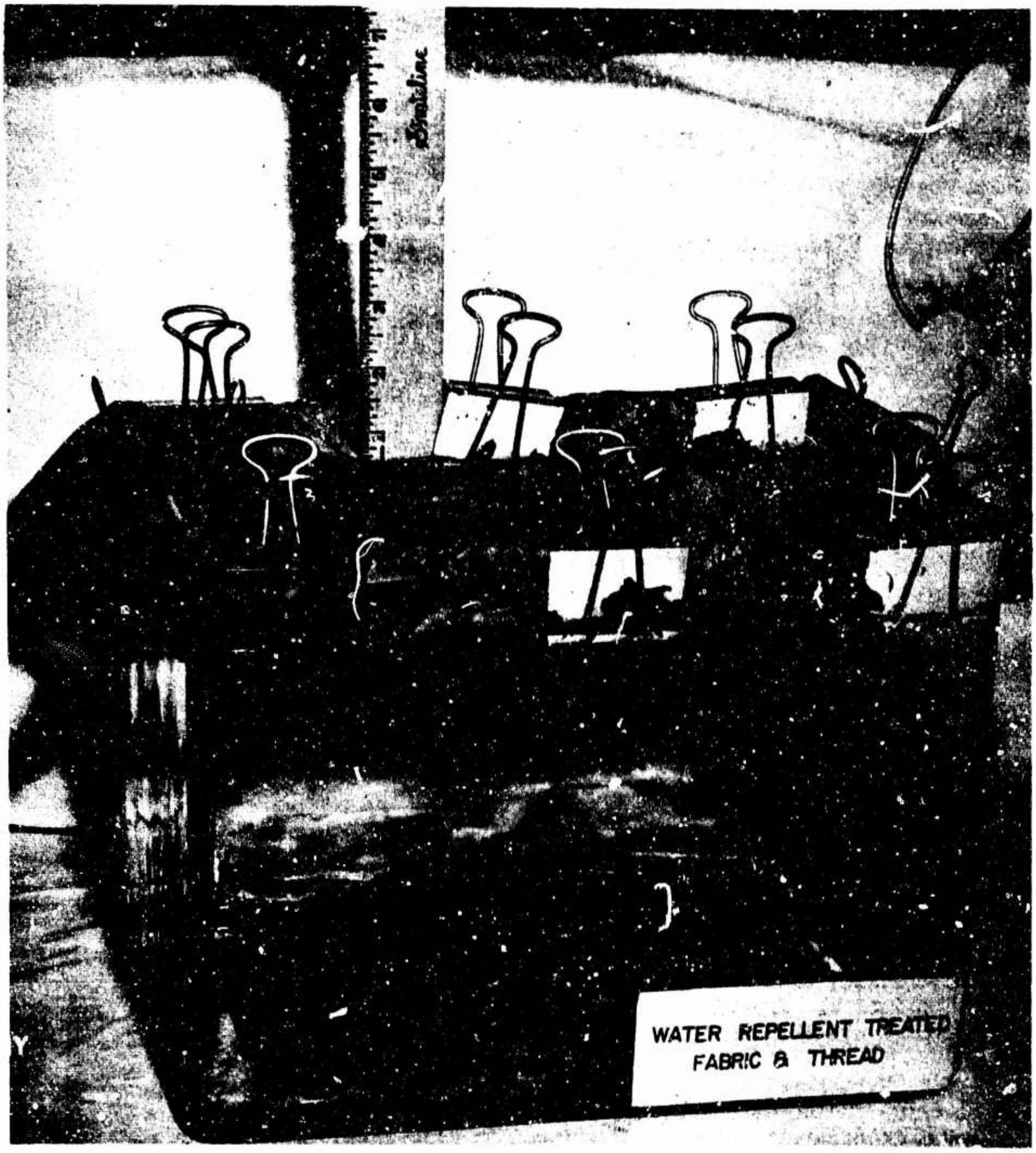


Figure 12. Jar Test Equipment

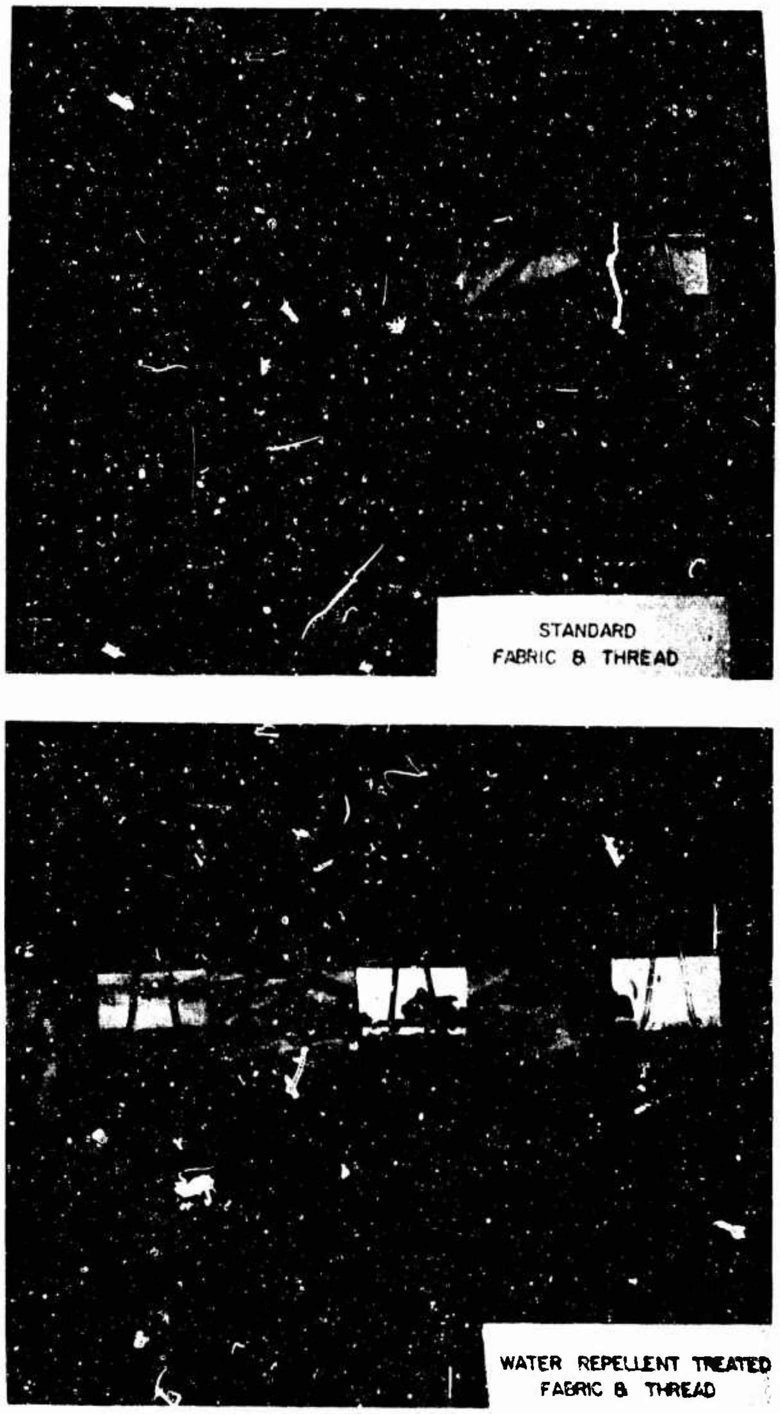


Figure 13. Comparison of Leakage in Seams Made With Standard (Non-Water Repellent Treated) Fabric and Thread With Seams of Water-Repellent Fabric and Thread

the coated fabric of the seam at a far greater rate. The water came through immediately so it was impossible to evaluate the part that each of the three potential mechanisms contributed to the overall leakage. Several specimens were tested in this manner with similar results. The specimens made with untreated coated fabric and water-repellent thread (Specimen #2) showed immediate leakage, but only through the folds of the fabric.

Specimen #3 which was made with water-repellent treated coated fabric and non-water-repellent thread permitted water to seep through the needle holes again by wicking of the thread in approximately 55 minutes. On the other hand, Specimen #4 (Figure 13) sewn with the water-repellent treated coated fabric and thread did not permit any leakage after 7½ hours. The latter specimen was permitted to remain in test for 48 hours and no leakage occurred during this time.

b. Rainroom Testing

Raincoats made with the standard untreated coated fabric and water-repellent treated coated fabric with water-repellent treated thread were tested in the rainroom at the U. S. Army Natick Laboratories. The coats were subjected to one inch per hour simulated rainfall on live test subjects and examined at 15 minute intervals. The results of these studies are summarized as follows:

(1) The raincoats made with the water-repellent treated coated fabric with no seam sealant kept the test subjects dry for a longer period of time than raincoats made with the untreated coated fabric and no seam sealant.

(2) Raincoats with one coat of seam sealant kept the subjects dry for a longer period of time than the same raincoats without the seam sealant.

(3) Raincoats with water-repellent treated coated fabric and one coat of seam sealant (on the main joining seams) protected the subjects for one hour exposure, whereas raincoats made with non-water-repellent coated fabric and one coat of sealant showed a small percentage of seam leakage.

(4) On all the raincoats (non-water-repellent coated fabric and water-repellent coated fabrics) which had seams sealed with two coats of sealant (on the sealable seams), no seam leakage occurred after one hour exposure in the rainroom. The raincoats with the water-repellent coated fabric showed slight leakage in

only one of 24 coats in the unsealed seams (collar stand joining seam, pocket, and pocket welt joining seam, and button stitching), whereas the raincoats with the untreated coated fabric showed slight leakage in the unsealed seams in 21 of 27 coats tested.

While these data show principally that sealed seams offered greater protection than unsealed seams, they also show that the water-repellent-treated coated fabric raincoats in unsealed seams were superior to the coats made of non-water-repellent treated coated fabric.

This investigation showed that the leakage of seams in a single coated fabric can be reduced by the application of a water-repellent finish to the coated fabric and the use of water-repellent thread. Accordingly, a policy was established to include requirements for water-repellency of the fabric and the thread in the raincoat specification. Because of the similarity of this fabric (1.6 ounce Butyl coated) to the single-coated, 1.1 ounce, rip-stop nylon fabric, these requirements were made part of the specification utilizing that fabric.

5. Tests of Various Seam and Stitch Types for Hydrostatic Resistance

a. Standard Seam and Stitch Types

There are two seam types ordinarily preferred for the manufacture of outerwear items that are inherently more water-resistant than all other commonly used seams. These are the double-felled, double-stitched type LSc-2 seam (Figure 6c) and the seam turned and raised stitched seam type LSq-2 (Figure 6d).

These seams are also preferred from a strength and durability standpoint as both are made with two rows of stitches. Under ideal conditions, the crosswise strength of the two are about equal. Seam type LSc-2 is generally preferred from the cost point of view as both rows of stitches are sewn simultaneously; whereas, the LSq-2 seam requires two separate sewing operations to put in the two rows of stitching. The seam type LSq-2 is usually preferred for commercial items because of its presumed better appearance (less puckering) than the type LSc-2 seam.

There are two major stitch types used in production sewing. They are stitch type 301 (Figure 6a) and stitch type 401 (Figure 6b). Stitch type 301, commonly called the lockstitch, is made with two threads: the solid lines represent the needle thread, and the hashed lines, the bobbin thread. The bobbin thread is sewn from

small bobbins under the bed plate of the machine. Figure 6b shows that stitch type 401 is also comprised of two threads. This stitch is generally preferred for production sewing because the looper thread is sewn continuously from large packages of thread (cones, tubes, and spools), whereas, the 301 stitch is more or less intermittent because the machine bobbins from which the bobbin thread is sewn hold only a relatively small amount of thread. These bobbins are wound on the machine during sewing and require frequent changing which reduces the effective running time of the machine during the course of the production day. Despite the difference in the cost factor between the two type stitches, the 301 stitch is preferred for making seam type LSq-2 and the stitch type 401 for the LSc-2.

b. Hydrostatic Test of Standard Seams

To permit a direct comparison of the relative hydrostatic resistance of the two stitch types, they were sewn down the center of three layers of the materials. This procedure eliminated the influence of leaking at the edges of the fabric. These specimens were tested along with specimens of seam types LSq-2 and LSc-2 in the following fabrics:

(1) 1.1-ounce rip-stop nylon coated on one side with polyurethane, water-repellent finished, finished weight approximately 2.5 to 3.25 ounces/square yard.

(2) 1.6-ounce nylon twill coated on both sides (one side containing a heavier coating) with polyvinyl chloride, having a finished weight of 6 to 7 ounces/square yard.

The single coated fabric described above was sewn with needles measuring 0.036 inch (across the blade) and the double-coated fabric was sewn with a needle measuring 0.040 inch because of its greater bulk. The thread used in all specimens was water-repellent treated cotton of ticket no. 50, three-ply for the top (needle), and bottom (bobbin) thread of stitch type 301 and ticket no. 50, three-ply as the top (needle) thread with ticket no. 70, two-ply as the bottom (looper) thread. Twelve stitches per inch were used in all the specimen seams.

Hydrostatic resistance tests were conducted on these specimens and the results are shown in Table IV.

TABLE IV

COMPARISON OF THE RELATIVE HYDROSTATIC RESISTANCE OF TWO STITCH AND SEAM TYPES IN TWO COATED FABRICS

Fabric	Urethane (Coated One Side) (cm)	Polyvinyl Chloride (Coated Two Sides) (cm)
Unseamed Fabric	No leakage at 50cm for 10 minutes	No leakage at 50cm for 10 minutes
Flat Fabric (3 Layers)		
Stitch type 301	30	17
Stitch type 401	34	20
Stitch and Seam Types		
301-LSq-2	9	11
401-LSq-2	10	13
301-LSc-2	12	13
401-LSc-2	14	15

Note: All results are the averages of three tests.

The hydrostatic test method requires that the seam withstand 50 cm of water for 10 minutes. During that period, if 3 droplets of water form in the seam area, the test specimen is considered to have failed and the seam is rated unsatisfactory.

The pressure of the test causes radial tension on the surface of the fabric and the seam exposed to the water. The tension, depending upon the resistance of the fabric, will open the interstices of the fabric and/or the needle perforations to allow water to flow through.

No consideration is given to the amount of water which passes through the seam. It could be a great amount through only one hole or a very small amount through several holes.

The above data show that there are small differences in the hydrostatic resistance between the stitch types 301 and 401 in the three-layer flat fabric specimens, and in the two seam types tested.

These differences are not considered important because of the low values obtained, but it is important to note the large differences shown between the two fabrics. The heavier double-coated fabric in the flat specimens show nearly 50 percent less hydrostatic resistance than the lighter single-coated fabric. This is no doubt attributable to the greater damage inflicted on the double-coated fabric in sewing. All leakage, of course, occurred through the needle holes.

In the case of the seams, there was no significant difference in the resistance of the two fabrics. The mechanics of leakage, however, was different for the two seams. The leakage occurred through the first stitching row of the LSq-2 seams, but the leakage in the LSc-2 seams occurred first between the layers of fabric in the seam and then, after a very short time, leakage took place through the needle holes. The first stitching of the LSq-2 seam (see arrow in the diagram of Figure 6d) was through only two layers of the material. In making this seam, the top layer of the fabric was turned over the stitching with some tension holes exposing the needle in only the one layer of fabric. Thus, the resistance to penetration of such a seam was expected to be low. On the other hand, three layers of fabric were in the seam type LSc-2. So, it should take more pressure to force the water through the needle holes in this type of seam; the results of the three-layered flat specimens confirm this. However, as was stated, the initial leakage occurred between the layers of fabric, but with an additional load of only 8 to 10 cm, the needle holes began to leak. In no case was the leakage through the needle holes confined to three or less holes; once the water came through, every needle hole leaked. The specimens of both fabrics behaved the same.

c. Test of Experimental Seams

From the foregoing discussion, it is obvious that two means of leakage must be stopped: (1) through needle holes, and (2) between layers of fabric in the seams. Several types of seams were made employing means to eliminate both sources of leakage.

Many variations of standard seams were made and tested in the jug test to screen out those which appeared to have no merit in the hydrostatic test. The LSq-type seams were abandoned because of the exposed row of needle holes in the single layer of fabric. Only three constructions appeared to have merit. One merit was to sew strips of Quarpel-treated cotton poplin into a type SSw-2 seam in an attempt to utilize the properties of that fabric to prevent leakage both through needle holes and among layers of fabric (Figure 14). A second approach was to sew a Quarpel-treated cord

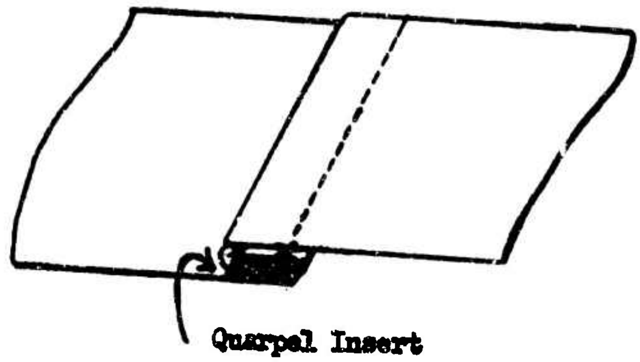


Figure 14. Seam Type SSw-2 With Quarpel Fabric Insert

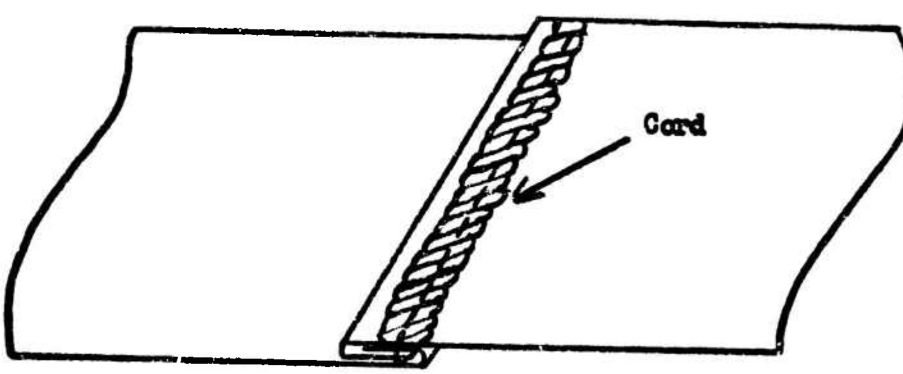


Figure 15. Seam Type LSc-1 With Quarpel Cord

on the top of an LSc-1 seam under the needle to jam the cord into the needle holes (Figure 15). A third method was to sew the type LSc-2 seam on a machine with a heated roll attachment (Figure 16) to determine if the vinyl coating could be softened enough to refill the needle holes. At the same time, it was considered possible that a slight bond could be obtained among the layers of the fabric which would prevent leakage occurring in this manner. The standard LSc-2 seam was used as the control. These seams were tested for hydrostatic resistance and the results are shown in Table V.

TABLE V

HYDROSTATIC RESISTANCE OF EXPERIMENTAL SEAMS

Seam Description	Hydrostatic Resistance in cm*
Control 401-LSc-2	15
LSc-1 w/Quarpel Cord	13
SSw-2 w/Quarpel Fabric	17
LSc-2 Heat Roll Treated	16

*Average of three specimens

In all the seams tested, the water first came between the layers of materials in the seam and after very short periods through the needle holes.

Despite the fact that gaskets of Quarpel fabric, and various thin synthetic rubber strips, both cured and uncured, such as neoprene and silicone rubber, were used, the pressures encountered in the hydrostatic tests were enough to cause these layers to separate and allow the water to go through. In some cases, it took longer for the water to come through the needle holes, but even these differences were not large enough to warrant further study.

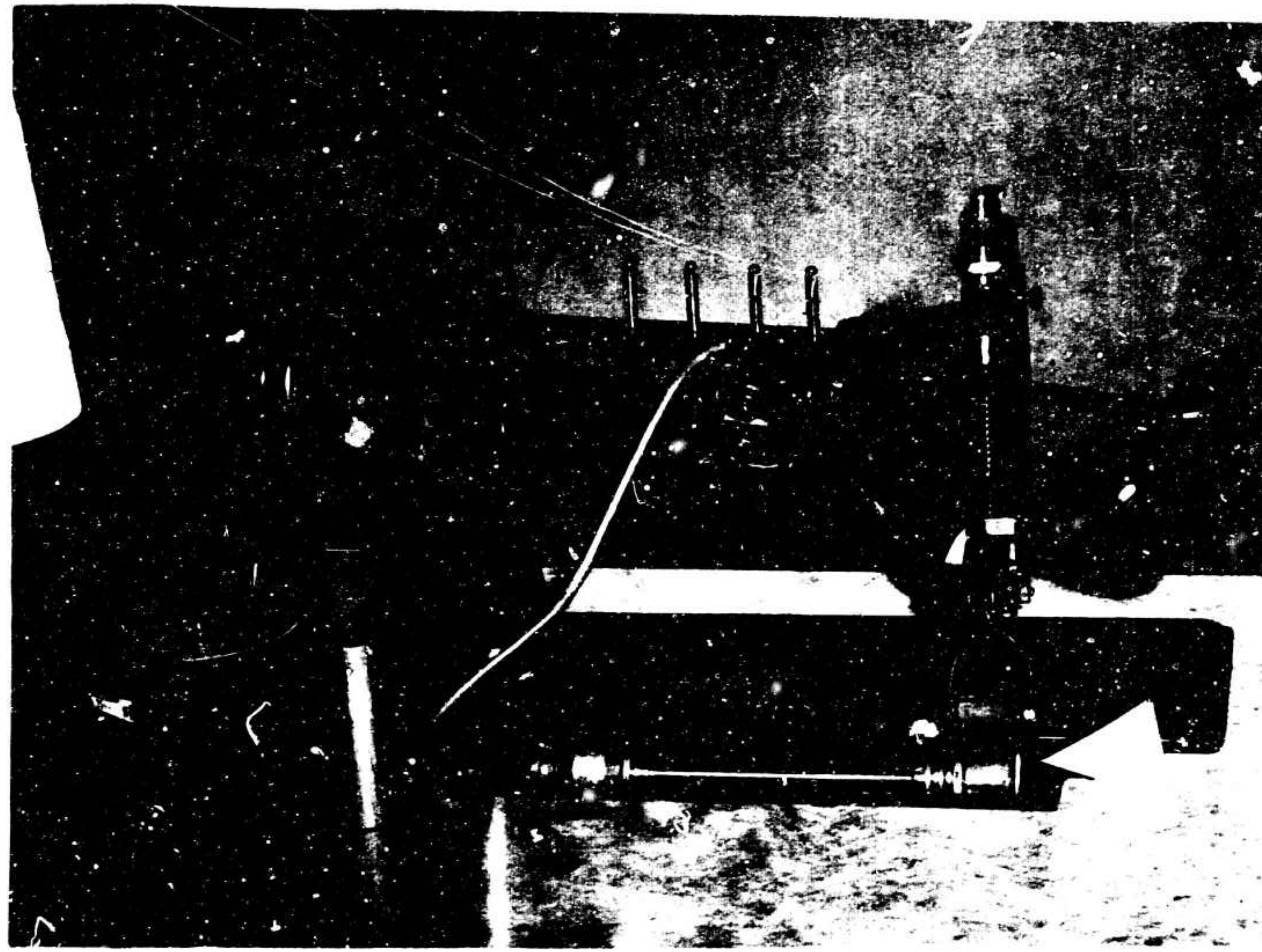


Figure 16. Sewing Machine With Heat Roll

Seams were also made using strips of polyvinyl alcohol films of different solubilities. The approach here was to have the film swell when it became wet to fill up the needle holes and space between the layers of fabrics. These seams appeared to show promise in the jar test where leakage occurred fairly early but appeared to lessen as time went on. However, the leakage did not stop over a period of six hours. In the hydrostatic test, the needle holes leaked early in the test and showed no effect of the swelling of the polyvinyl alcohol film in reducing the leakage over a 5-minute period.

d. Wet Sand Test

The poncho has three principal uses: (1) as an overall body cover; (2) for tents and lean-tos; and (3) as a ground sheet. In uses 1 and 2, the poncho is subjected to various degrees of rainfall. In the third use, the poncho is laid on damp or wet ground. If pressure is placed upon the poncho seams, then water is pressed through the seam. A laboratory test utilizing wet sand was devised to test the resistance of various seam constructions to ground moisture.

Sand was placed in a laboratory tray approximately 12 inches x 9 inches x 4 inches deep and wet down until saturated, leaving a film of water of approximately 1/16-inch on top of the sand. A small amount of pure blue dye was placed in the water. The seam specimens were placed with the outside of the fabric and seam toward the sand. Three-inch squares of blotting paper were placed on the seam and weights equivalent to 0.74 psi were placed on the blotters. The LSc-2 seams were tested in Quarpel-treated cotton poplin and in the single and double coated fabrics. The weights and blotters were removed after one minute and the blotters were inspected for leakage. The leakage showed on the blotter in the form of blue dots which indicated water had been forced through the needle holes by the pressure.

Very light staining was observed on the blotters placed on the seams in the Quarpel fabric after the first minute; it progressed rather slowly over a 10 minute span. On the other hand, the leakage in the first minute on the seams of both the coated fabrics was substantially greater. The colored water forced through the seams spread rapidly in the blotters and the area of staining was compared by measuring the diameter of the dots. The diameter of the stains found with the Quarpel fabric measured less than 1 mm in diameter after the first minute and approximately 1.5 mm after 10 minutes, but the stains on both coated fabric seams measured approximately

1.5 after the first minute and progressed to nearly 3.0 mm after 10 minutes. After the five-minute period, the stains spread irregularly through the blotter making an accurate measurement impractical. Seepage through the folds of the seam was very slight and inconsequential in this test. The three-layered specimens of the coated fabrics were also tested in this manner and the results showed no measurable differences between fabrics nor between stitch types. The magnitude of leakage through the needle holes was equivalent to that found with the seams.

This method has no significant value other than to further show that water can penetrate needle holes made in the coated fabrics more easily than through a tightly woven, well-treated, water-repellent cotton poplin fabric.

6. Conclusions

Data presented in this study show the greatest causes of leakage in seams of coated fabric are the enlarged needle holes caused by sewing damage to the fabric and coating and the seepage of water under pressure through the folds of fabric in the seams.

The extent of sewing damage is primarily related to the coated fabric properties; needle size and other machine components, such as presser feet, throat plate holes, and feeds (if properly selected and utilized), contribute little to the leakage.

The stitch and seam types show only minor differences in seam leakage under low hydrostatic pressure, but the 401 stitch and the LSc-2 combination result in the best seam.

The seams in double coated fabrics fail at little more than half the hydrostatic resistance of the same seams in the single coated fabric due to the greater sewing damage in the double coated fabrics.

The standard stitch type 401 seam type LSc-2 seam leaks less than any other seam evaluated to date.

It does not appear possible to develop seams for coated fabrics which would meet the present requirement for low-pressure hydrostatic resistance without sealing within the present state of the art.

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13. ABSTRACT

Extensive investigations of sewn seams in coated fabrics have been conducted. The relative roll of thread, sewing machine components, stitch and seam types and properties of fabrics have been evaluated as parameters involved in seam leakage. Utilization of various experimental seam constructions, gasketing, application of heat during seam sewing and other techniques were attempted as potentially useful approaches in combating seam leakage.

Results indicate the main source of leakage, under experimentally generated hydrostatic pressure conditions, to be in the folds of the fabric and the needle holes generated in the sewing operation. Post sealing, accordingly, must be considered to be a necessary requirement for all coated fabrics to assure moisture-proof seams under field use conditions.

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Sealing	8					
Waterproofing	8					